Q 58: Photonik 3

Time: Friday 10:30–13:00 Location: V38.01

Group Report Q 58.1 Fri 10:30 V38.01

Progress report towards strong light-matter coupling in free space: A single ion and a single photon — •Robert Maiwald[1,2], Andrea Golla[1,2], Martin Fischer[1,2], Marianne Bader[1,2], Benoît Chalopin[3], Simon Heugel[1,2], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Institut für Optik, Information und Photonik (IOIP), Universität Erlangen-Nürnberg, Erlangen — [2]Max-Planck-Institut für die Physik des Lichts (MPL), Erlangen — [3]Laboratoire Collisions Agrégats Réactivité, Université Paul Sabatier, Toulouse, France

An optimized process of light-matter interaction is crucial for applications such as quantum memories, gate operations and entanglement distribution. Our contribution to this field focuses on the efficient interaction of light with single atomic ions in free space. To this end we have devised a coupling scheme based on a parabolic mirror surrounding an ion [1, 2]. This setup converts a radially polarized Laguerre-Gaussian light field into a linear polarized dipole mode concentrated in the mirror's focus, where an ion trap with high optical access is used to localize a single ion [3]. Our primary goals are twofold: (i) reaching maximum possible phase shift of a coherent light field based on the state dependent interaction with a single atom; and (ii) demonstrating that a single photon can deterministically excite an atom in free space. Both questions require different scenarios, the latter one being the time-reversed version of spontaneous emission. In the talk we review theoretical expectations and present recent results from our experiments, ranging from spatial and temporal pulse shaping of light to match the ion's transition wavelength and lifetime, all the way to the successful trapping of single $^{174}Yb^{+}$ ions inside the parabolic mirror, where we compare the measured fluorescence rate to the absolute rate possible.

[1] M. Sondermann *et al.*, Applied Physics B, **89** (4), 489-492 (2007)
[2] N. Lindlein *et al.*, Laser Physics, **17**, 927-934 (2007)
[3] R. Maiwald *et al.*, Nature Physics **5**, 551 (2009)

Q 58.2 Fri 11:00 V38.01

Fiber-coupled ion as a single photon source — Hiroki Takahashi, Andrew Riley-Watson, •Matthias Keller, and Wolfgang Lange — University of Sussex, Brighton, BN1 9QH, United Kingdom

We have realized a compact system combining an ion-trap with a pair of optical fibers. The fibers are tightly integrated in the center electrodes of a miniature endcap trap. In this way, we have coupled single photons emitted by the ion on demand to the two fibers. The total capture efficiency corresponds to 6% of the solid angle. The high collection efficiency and high signal-to-background ratio make the setup an ideal quantum light source. We have measured pulse shapes and second-order correlation function of the photons in the fiber. The system provides an interface between single-ion physics and photonics. It has a range of applications including single-ion spectroscopy, state detection in quantum information processing, strong coupling cavity-QED with ions and quantum repeaters.

Q 58.3 Fri 11:15 V38.01

Rydberg Blockade in a hot Vapor – Optimal Control Approach towards a Single Photon Source — •Matthias Müller[1], Simone Montangero[1], Andreas Kölle[2], Robert Löw[2], Tilman Pfau[2], and Tommaso Calarco[1] — [1]Universität Ulm — [2]Universität Stuttgart

Rydberg Atoms are a promising approach to an implementation of quantum computational building blocks [Rev. Mod. Phys. 82, 2313-2363 (2010)]. Their long-range state-dependent interaction allows to establish entanglement over extended samples. One major concept is the usage of the so-called Rydberg blockade preventing multiple excitation of atoms inside a blockade sphere into the Rydberg state as the interaction potential moves doubly excited states out of resonance.

This effect can be used to create a W-state with one single excitation and an imprinted phase and thus an imprinted direction of the photon obtained by spontaneous collective emission of the W-state. A single photon source like this is a key element of quantum information transfer, also in the framework of quantum repeaters.

In my talk I will show how the implementation of this idea depends on optimal control theory and what improvement this technique yields.

Q 58.4 Fri 11:30 V38.01

Remote atom-atom entanglement — •Michael Krug[1], Julian Hofmann[1], Norbert Ortegel[1], Lea Gérard[1], Kai Redeker[1], Florian Henkel[1], Wenjamin Rosenfeld[1,2], Markus Weber[1], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Entanglement between atomic quantum memories at remote locations will be a key resource for future applications in quantum communication, especially for the quantum repeater. One possibility to generate such entanglement over large distances is entanglement swapping starting from two quantum memories each entangled with a photon. The photons can be transported easily to a Bell-state measurement where after the memories are projected onto an entangled state.

We have set up two independently operating atomic traps situated in two neighboring laboratories separated by 20 m. Via a spontaneous decay process each quantum memory, in our case a single ^{87}Rb atom, emits a single photon whose polarization is entangled with the atomic spin. For Bell state measurment interference of the two photons at a beam splitter is employed. Conditioned on the registration of particular two-photon coincidences the spin states of both atoms are measured. The observed correlations clearly prove the entanglement of the two remote atoms. This is a first step towards creating a basic node of a quantum communication network as well as a key prerequisite for a future loophole-free test of Bell's inequality with entangled pairs of neutral atoms.

Q 58.5 Fri 11:45 V38.01

Entanglement generation by resonant photon exchange in a hybrid quantum repeater — •Joszef Bernad and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt

The realization of a quantum repeater capable of creating entanglement between qubits over large distances still represents a major quantum technological challenge. In this context the recent proposal of van Loock et al. [1] of a hybrid quantum repeater in which continuous variables of the electromagnetic field exchange quantum information with spatially separated material qubits offers interesting perspectives for preparing highly entangled material qubit pairs over large distances.

In this contribution we extend this proposal of van Loock et al. to cases in which the interaction between the material qubits and the photons is resonant but sufficiently short so that effects of spontaneous decay can be neglected. It is demonstrated that this way the probability of creation of high-fidelity Bell-states between the two spatially separated atomic qubits can be increased in comparison with the off-resonant cases considered so far [1]. Results on maximum achievable success probabilities of creating high-fidelity Bell pairs are presented. Furthermore, also effects originating from loss in the connecting optical fiber are discussed.

[1] P. van Loock, T.D. Ladd, K. Sanaka, F. Yamagouchi, , K. Nemoto, W. J. Munro, and Y. Yamamoto, Phys. Rev. Lett. 96, 240501 (2006).

Q 58.6 Fri 12:00 V38.01

Four state discrimination via a hybrid receiver — •Christian R. Müller[1,2], Mario A. Usuga[3,1], Christoffer Wittmann[1,3], Masahiro Takeoka[4], Christoph Marquardt[1,3], Ulrik L. Andersen[3,1], and Gerd Leuchs[1,3] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg, Germany — [3]Department of Physics, Technical University of Denmark, Kongens Lyngby, Denmark — [4]National Institute of Information and Communications Technology, 4-2-1 Nukui-Kita Koganei, Tokyo 184-8795, Japan

According to the basic postulates of quantum mechanics, perfect discrimination of nonorthogonal quantum states is impossible and strict bounds apply for the minimum error rates that can be achieved [1]. Little attention has so far been devoted to the development of discrimination protocols for multi-letter alphabets [2]. We propose and experimentally demonstrate a near optimal hybrid discrimination scheme for the quadrature phase shift keying protocol (QPSK). We show in theory and by means of experimental results that the performance of our scheme is superior to the standard approach - heterodyne detection - for all signal amplitudes. The discrimination is composed of a quadrature measurement, a feed forward and a photon detection.

[1] C. W. Helstrom, Mathematics in Science and Engineering (Academic, New York, 1979), Vol. **123**

[2]S. Lorenz, N. Korolkova and G. Leuchs, Appl. Phys. B, **79** (3), 273 - 277 (2004)

Q 58.7 Fri 12:15 V38.01

Controlling the Phase of a Light Beam with a Single Molecule — •Andreas Maser[1], Martin Pototschnig[2,3], Yannick Chassagneux[4,3], Jaesuk Hwang[5,3], Gert Zumofen[3], Alois Renn[3], and Vahid Sandoghdar[1,3] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Norman Bridge Laboratory of Physics 12-33, California Institute of Technology, Pasadena, California 91125, USA — [3]Laboratory of Physical Chemistry, ETH Zurich, 8093 Zurich, Switzerland — [4]Laboratoire Pierre Aigrain, Ecole Normale Superieure, 75231 Paris Cedex 5, France — [5]Department of Physics, Imperial College, London, United Kingdom

Single optical emitters such as atoms, ions, molecules, quantum dots, and color centers have been most commonly detected via their fluorescence emission. However, the fluorescence signal fails to access the coherent features of the interaction between the emitter and the incident light. We investigate both the amplitude and the phase involved in the coupling of a single molecule and a weak laser beam. An attenuation of up to 20% and a phase shift larger than 3° is observed.

We use this effect to record the first phase-contrast images of single molecules. Furthermore, by applying a voltage to the microelectrodes embedded in the sample we demonstrate a single-molecule electro-optical phase switch. Our results may find applications in single-molecule holography, fast optical coherent signal processing, and single-emitter quantum operations [1].

[1] M. Pototschnig *et al.*, Phys. Rev. Lett. **107**, 063001 (2011)

Q 58.8 Fri 12:30 V38.01

Formation of supermodes in atom-microcavity chains — •Sandra Isabelle Schmid and Jörg Evers — Max-Planck Institut für Kernphysik, Heidelberg, Germany

We investigate pathway interference effects in a chain of coupled atom-cavity systems[1]. Each subsystem consists of a whispering gallery resonator coupled to a nearby two-level atom. The subsystems are connected by a common fiber which allows to probe the system by an input laser field. Photon fluxes between the atom-cavity subsystems are possible in both directions. We found, that this energy exchange between the subsystems influences strongly the system's dynamics. This enables the formation of so-called supermodes which lead to a strongly enhanced transmission signal as compared to a chain of independent atom-cavity systems, where backward fluxes are suppressed. Interference effects of different pathways, as they were also analyzed in [2], on which light can propagate through such a coupled setup play a key role in the system's dynamics. The impact of the formation of supermodes increases with the chain length for long chains and leads to a crucially enhanced relative transmission output. While the transmission signal serves as indicator for supermodes, the reflection signal could be used in order to detect, which cavities of the chain couple to nearby atoms. This information can be crucial in experiments where simultaneous coupling of the atoms is difficult.

[1] S. I. Schmid and J. Evers, arXiv:1108.4525 [quant-ph] (2011).

[2] S. I. Schmid, K. Xia, and J. Evers, Phys. Rev. A 84, 013808 (2011).

Q 58.9 Fri 12:45 V38.01

Poling properties of Ti-diffusion-doped $LiNbO_3$ — •Christof Eigner, Raimund Ricken, Viktor Quiring, Hubertus Suche, and Christine Silberhorn — Integrated Quantum Optics, Applied Physics, University of Paderborn, 33098 Paderborn, Germany

Guided wave nonlinear optical frequency conversion, which utilizes domain gratings for quasi-phase matching, promises high efficiencies if low loss waveguides and homogeneous domain gratings can be fabricated. Ti-indiffused channels in congruent $LiNbO_3$ (CLN) are promising waveguides as they provide very low loss and guiding in both, TE- and TM-polarization. However, periodic domain inversion by field assisted poling differs significantly from the poling properties of undoped virgin $LiNbO_3$. Especially, poling of homogenous short period domain structures, e.g. for the interconversion between short (UV) and long (telecom) wavelengths, is challenging. In this work, the influence of the Ti-doping on the coercive field strength is investigated and a set-up for pulsed field-assisted poling has been tested. Significant increase of the coercive field strength of the Ti-doped compared to the undoped CLN has been observed.